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Wild boar movement monitoring for African swine fever control along the Sino-Russian and Korean border

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ABSTRACT
African swine fever remains a severe threat to the swine industry globally. The habitats similarities and wild boar populations along the Sino-Russian and Korea border and the possibilities that infected Wild boar may cross the border raised a big concern. For the prevention and control of transboundary transmission of ASF, reliable information on wild boar movement and habitat utilization is needed but insufficient. For this study, we deployed a Global positioning system satellite (GPS) collar and utilized marked baits mixed with animal feed for wild boar movement monitoring. Our result shows that the GPS satellite collar recorded the maximum daily movement 4.02 ± 0.8 km and 4.6 ± 0.9 km for female and male wild boar, respectively. Both wild boar spent most of their activities at a low elevation closer to the capturing site. The marked bait technique indicated the average dispersal distance of wild boar away from the baiting site was 6.4 ± 0.3 km. We conclude that in a natural condition, African swine fever transmission along across a continent for a long distance is by the wild boar movement is unlikely.

Keywords: African swine fever; GPS satellite collaring, marked bait, wild boar movement

1. INTRODUCTION
Wild boar (*Sus scrofa*) is known for its large geographic distributions and change its activity with the intensity of human disturbance. It occurs in pure wild or barely modified feral form on all continents, except Antarctica and many oceanic islands, and shows remarkable flexibility in its ecological and behavioral traits (Chiba, 1964; Oliver and Leus, 2008). Wild boar social structure centered at maternal with a strong relation between sows and piglets (Keuling et al., 2010; Truvé et al., 2004), while adult males are solitary outside of the rutting period (Said et al., 2012). The dispersal rate of wild boar generally varies depending on sex (Truvé and Lemel, 2003), with young males being the most common disperser (Keuling et al., 2010). Contrary to this, some studies showed that in Spain and Slovenia, females dispersed the longest distance (Casas-Diaz et al., 2013). Wild boar can adapt to different habitats, eat almost anything that fits the mouth, and runs fast as well as swim and

crossing the river too (Chiba, 1964; Oliver and Leus, 2008). However, roads and railways may present boundaries to the wild boar movement; thus might inhibit wild boar from entering an area or crossing into new regions (Wyckoff et al., 2012).

Wild boars prefer habitat with dense vegetation, water for thermoregulation and lush vegetation, and high mast production for forage. Accordingly, seasonal food availability, shelter, and water distribution may influence the wild boar movement (Wyckoff et al., 2012) and home range (Keuling et al., 2009). In European countries, with unrestricted hunting pressure, wild boar move over long distances and can disperse to occupy larger spaces (Oliver and Leus, 2008).

The main concern with wild boar is its ability to sustain and spread African swine fever (ASF) virus across continents (Lavelle et al., 2018; Wyckoff et al., 2012). Besides, wild boar serve as reservoirs of pathogens within which vector-borne diseases persist. Recently, ASF is the main threat for wild boar conservation because of its high mortality and the recommended wild boar population reduction as the control method for ASF. Nevertheless, the number of wild boar populations is increasing, probably due to the loss of their key predators and their highly prolific nature (FAO, 2014). In China, wildlife and nature protection laws strengthened since 1989. Consequently, hunting of wild animals banned and considered illegal. Due to this, the wild boar population became increasing (Cai et al., 2008).

An increase in population of wild boar and its potential role in transboundary transmission of ASF have raised great concern. For the prevention and control of ASF transmission, reliable information on wild boar movement and habitat utilization is needed but insufficient, especially in our study area NE China. Therefore, this study will be useful to provide up-to-date information on the activity of wild boar along the Sino-Russian and Korean border.

Studies of the animal movements often include radio-telemetry, trapping, and direct observation of marked individuals. For this study, we deployed Global positioning system (GPS) satellite collars and utilized marked bait for wild boar movement monitoring. GPS satellite collars had been used on many vertebrates worldwide for movement monitoring and home range determination (Baubet et al., 2004). Moreover, for the purpose of distinguishing between individual wild boar feces (Fuller et al., 2011), we used marked baits mixed with animal feed (Delahay et al., 2000). The bait-marking method can provide necessary information on wild boar mobility and does not require sophisticated material (Delahay et al., 2000; Lavelle et al., 2018). Therefore, our objective was to assess wild boar daily movement near the Sino-Russian and Korean border, calculate the home range and compare the practicability of the two methods used in this study.

2. METHODOLOGY

Research Area

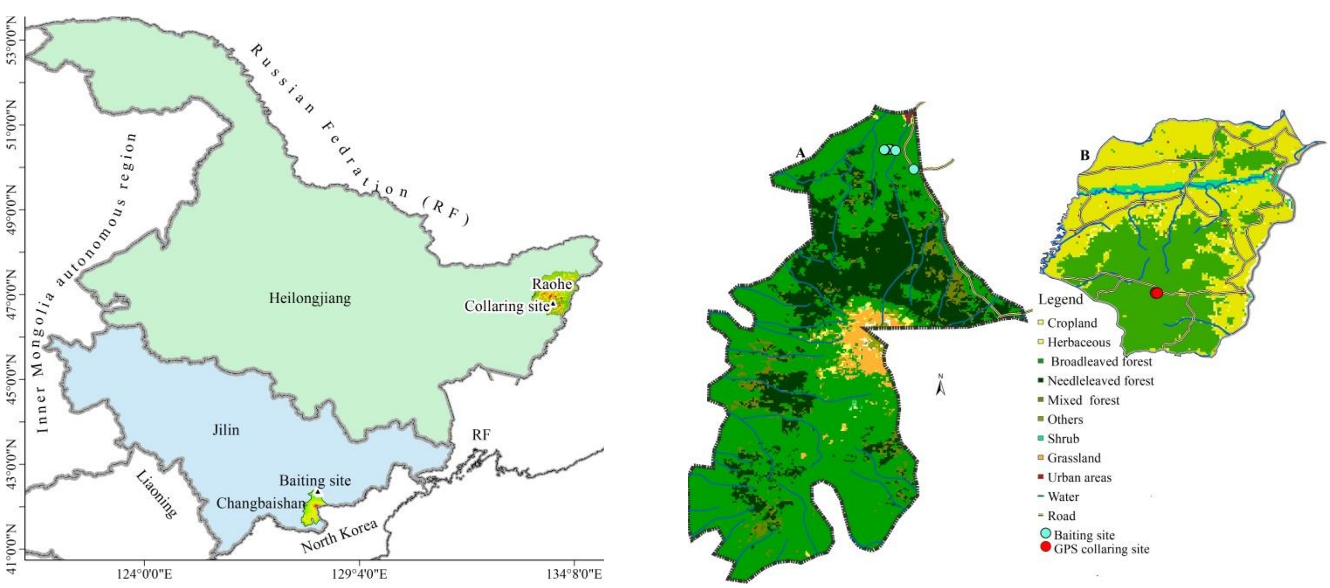

Fig.1 Collaring and bait delivery areas. (A) Landscape patterns of CMNR, (B) Landscape patterns of Raohe County

For wild boar movement monitoring, we selected two sites along the Sino-Russia and Korean borders (Fig. 1). The first site was Changbai Mountain Nature Reserve (CMNR), situated in the southeastern part of Jilin City, Antu County of Yanbian Korean

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Autonomous Prefecture in NE China, bordering North Korea in the south. CMNR has a temperate continental climate characterized by long and cold winter, short and cool changeable wet summer, windy spring, and foggy autumn, with an annual average temperature of -7 °C to 3 °C. Under the impact of vertical changes of mountainous terrain, four altitudinal vegetation zones from the bottom to the top of the mountain: including broad-leaved and Korean pine mixed forest, dark coniferous forest, Erman birch forest, and alpine tundra (Yu et al., 2011, 2004). The second site was Raohe County, located in the northeast section of WanDashan in Heilongjiang Province at the middle and lower reaches of the Ussuri River on the borderline with Russia. The east and north parts of Raohe are plains, and the west and south are mountainous areas. The terrain is complex, tilting from southwest to northeast. The landscape is diverse and divided into four types: mountain hills, terraces, plains, river marshes, and floodplains (Carroll and Miquelle, 2006).

Methods

GPS satellite collar deployment

In Raohe County, Heilongjiang Provence, NE China, two healthy nonbreeding wild boars, GPS ID 2268, weighing 82 kg, an adult female herein after –female wild boar, and an adult male GPS ID 2289, weighing 84 kg herein after-male wild boar were fitted with GPS satellite collars. The female wild boar collar started recording the data from 30/07/2018 and the male wild boar collar from 12/08/2018. The GPS satellite collars were programmed to collect and store one data point every 2 hours and gave 12 readings per day. The GPS satellite collar collected information on animal movement location, temperature, speed, and elevation. To calculate the home range, data was downloaded and imported to Range 8 demo version for location analysis. The home-range size was calculated for each month and estimated by the 100% Minimum Convex Polygon(Russo et al., 1997). We calculated the daily movement in ArcGIS 10.3 Desktop (ESRI, Redlands, CA, USA).

Bait delivery for wild boar

The field study for the bait delivery in CMNR was conducted in December 2017. The study was set on two randomly selected channels in the east slope of CMNR. The bait delivery sites were selected based on the high observation rate of wild boar activities (rooting, feces, and track) as per the information from CMNR workers. In this survey, a type of plastic beads commercially available in toy stores selected as markers. These beads were cylindrical, approximately 3 mm in diameter and 5 mm long with a different color. The plastic beads were soft, non-toxic, and vicious enough not to break when the boars chew. These markers showed no alterations in color and seemed to have passed unaffected through the Wild boar facess (Öhmark, 2006). To make the bait more palatable and consumed by Wild boar, we mixed it with corn, peanut, and vegetable oil. We thoroughly mixed 10kg of corn with 1kg of markers in a plastic bucket (Fig.2). On each feeding site, we placed the mixture in ten piles with approximately 1kg per pile. Following the bait deployment, the feeding site was inspected early in the morning. After the bait was consumed, the grounds surrounding the feeding sites were thoroughly examined for wild boar feces and a GPS reading of each pile of wild boar feces was recorded to determine the distance from the baiting site to the farthest and nearest drop spotting site. To monitor the consumption of baits by wild boar, we used the camera traps at each baiting site (Fig.3).

Fig.2 A) Bait placement, B). Red and green bait mixed with corn and peanut in the bucket

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Fig. 3 Camera trap for monitoring

3. RESULTS

GPS satellite collaring

The female wild boar collar and the male wild boar collar collected the daily movement for 6 and 9 months, respectively. Female wild boar collar recorded the data from 30 July 2018 to 26 February 2019 and the male wild boar collar from 12 August 2018 to 23 April 2019. Both GPSs effectively recorded information on wild boar movement location, elevation, speed, and environmental temperature. Totally (n=2042) locations were recorded by male wild boar collar and (n=1245) by female wild boar collar. The tracking result from the male wild boar collar showed that the total home range and the maximum daily movement were 189.3 m^2 and 4.6 km, respectively (Table 1 and 2). While for the female wild boar collar, the total home range and the maximum daily movement was 6.08 m^2 and 4.02 km (Table 1 and 3). The two wild boar spent most of their activity near the capturing site (Fig.4) between the altitudes of 100-200 m (Fig.5) with a minimum displacement velocity (Fig.6).

Table 1 Daily movement of the GPS satellite collard wild boar

Distance	Female	Male	unit
Mean	1.6	0.8	km/day
Minimum	0.02	0.04	"
Maximum	4.02	4.6	"
SD	0.8	0.9	

Table 2 Monthly home range for male wild boar

Month	year	unit	Area
August	2018	m^2	182.26
September	2018	"	1.013
October	2018	"	1.014
December	2018	"	1.001
January	2019	"	1.003
February	2019	"	1.002
March	2019	"	1.004
April	2019	"	1.004
Total		"	189.3

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Table 3 Monthly home range for female wild boar

Month	year	unit	Area
August	2018	"	1.015
September	2018	"	1.014
October	2018	"	1.015
November	2018	"	1.014
December	2018	"	1.014
January	2019	"	1.012
Total			6.08

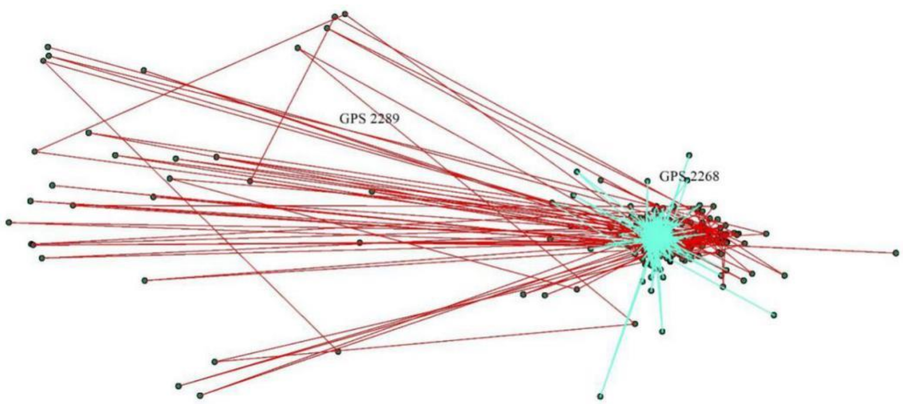

Fig.4 Movement patterns of collared wild boar female and male during the study period

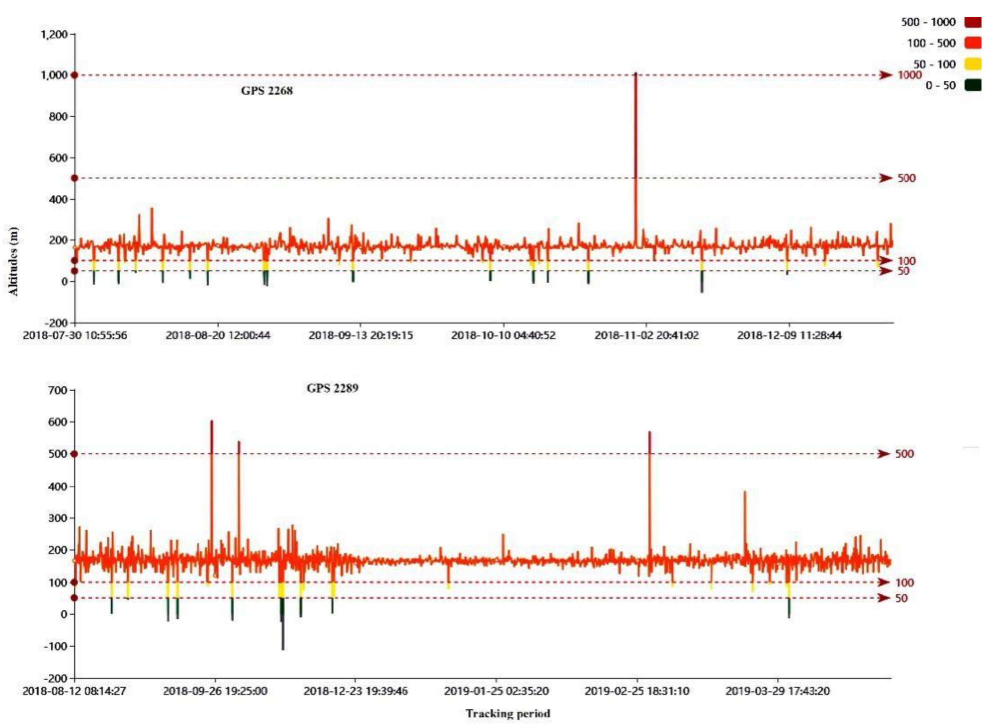

Fig. 5 Elevation range for female (GPS 2268) and male (GPS 2289) wild boar movement

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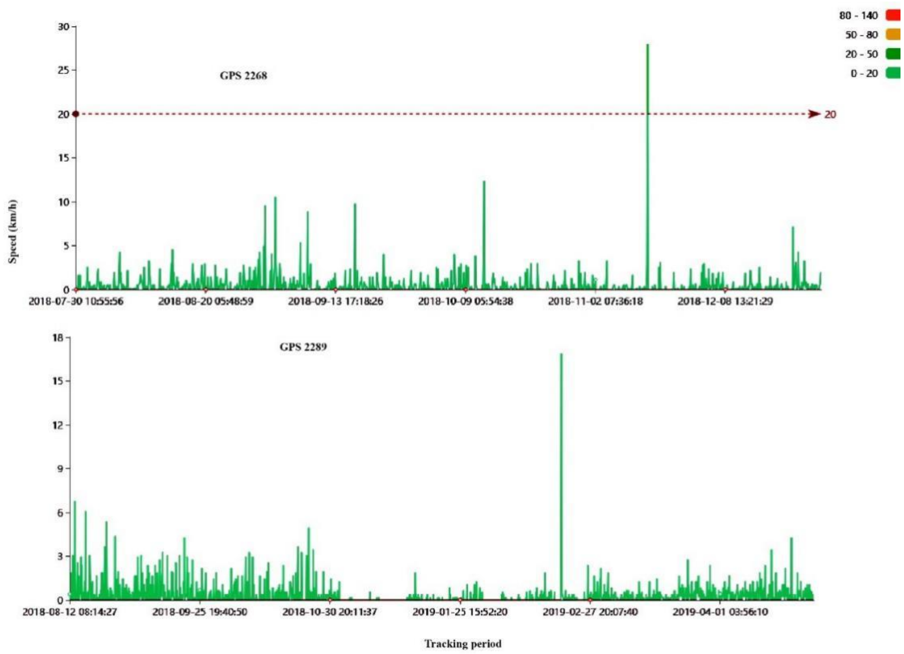

Fig.6 Speed of the two wild boar movement female (GPS 2268) and male (GPS 2289)

Bait recovery

The bait was recovered from one feeding site out of the two (Fig.7). After consumption by wild boar, the bait was found in wild boar feces within the distance of 6.1, 6.5, and 6.7 km away from the feeding site (the mean distance 6.4 ± 0.3). At the first feeding site, the bait was consumed by wild boar successfully, although recovery was unsuccessful. The camera traps showed that all the bait was consumed successfully (Fig.8).

Fig.7 Bait recovered in wild boar feces

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Fig.8 Wild boar consuming the bait as monitored by camera trap

4. DISCUSSION

GPS satellite collaring

Wild boar is known to be a reservoir for a several pathogens (Casas-Diaz et al., 2013) and the most extensively distributed terrestrial mammals in the world (Barrios-Garcia and Ballari, 2012), which is known to change its activity pattern with the intensity of human disturbance (Ohashi et al., 2013). In an area with regular hunting pressure, wild boar is spatially unstable, which results in an increased distance between consecutive resting sites (Scillitani et al., 2010). In this study, both bait and GPS satellite collaring tracking techniques employed to monitor wild boar movement illustrated that wild boar in our study area was stable and not moved a long distance from the baiting and collared site. Although the two GPS collected the movement data unevenly because of the failure of female wild boar collar after six months, the daily movement and home range covered by the female wild boar was comparatively less than that of the male (Table 1,3, and Fig.4). The monthly home range for the two wild boar was similar except a comparatively larger recorded during August for male (Table 2). Our result indicated that the monthly home range of the two wild boar was pretty small compared to other studies (Russo et al., 1997). Nevertheless, the wild boar home range may change depending on the availability of feed, human disturbances (Keuling et al., 2008), shelter (Ohashi et al., 2013), sex, and population density (Scillitani et al., 2010). Marked seasonal variation of the home range due to environmental factors had also been described elsewhere in the literature (Keuling et al., 2008).

The daily movement of wild boar in this study coincides with the average daily movement in Romania but contradicts with dispersal rate in Germany. Wild boar show notable intraspecific differences in spatial behavior across various geographic locations and habitats (Fattebert et al., 2017; Podgórski et al., 2012), with the average daily movement varied between 3.6 to 4.8 km (Fodor et al., 2015). The wild boar movement relative to sex and age ranged from 0.18 to 41.5 km. Generally, males dispersed longer distances than females and Piglets (Keuling et al., 2010). Wild boar show strong site fidelity and their social structure centered around matrilineal groups (Śmietanka et al., 2016). The small home range and minimum daily movement of wild boar in this study corroborate wild boar stay within 1-2 km of their natal home ranges (Fattebert et al., 2017; Podgórski et al., 2012). The limited activity of wild boar in our study area may be due to habitat fragmentation, which hinders the utilization of all available habitats. Human cased habitat fragmentation has a significant effect on the activity of wild boar due to the creation of patchy resource distribution and barriers that constrain wild boar movements (Podgórski et al., 2012). On the other hand, the small home range and minimum daily movement in this area may be explained by a low anthropogenic disturbance since it is located mostly surrounded by mountain ranges with considerable forest coverage. Wild boar movement is initiated by external factors, internal factors, navigation, and motion (Nathan et al., 2008). The GPS satellite collar has become a vital wildlife study method worldwide because of the advantages of automated tracking of animal movements and high location accuracy (Jiang et al., 2012). For an animal like wild boar that can eat the baits, various marker substances can be provided (Delahay et al., 2000) for daily movement monitoring, which helps to distinguish between different individual feces (Fuller et al., 2011).

Bait recovery

The bait delivering technique provided important information on wild boar movement and it does not require special equipment

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(Delahay et al., 2000; Lavelle et al., 2018). The experiment done in this study during the bait delivery showed a promising result for easy monitoring of wild boar movement. Especially, the addition and mixing of corn, peanut, and vegetable oil improved the palatability of the bait. Because of this wild boar regularly visited the baiting site to consume the feed. Therefore, compared with the GPS satellite collaring the baiting method, if extensively used was less labour intensive and more covenant for study animals. However, it is laborious for personnel in an area with dense forest cover and in a bad climatic condition. One of its drawbacks was that during the winter if the snow fails after the animal consumed the bait; it was difficult to track the animal because of the snow cover. Even though it provides scientific data on animal movement and environment, the GPS collar is a burden for collared animals and persons involved in the capturing during the fitting of the collar. The Wild boar preferred to spend most of its time resting under the shade after collaring, which reduces the signal of the GPS, especially in the forest area.

5. CONCLUSIONS

Our result clearly show that wild boar NE China does not cross the Sino-Russia and Korean border, indicating that the risk of transboundary transmission of Africa swine fever is unlikely unless anthropogenic factors initiated them to move long distances. Thus, the knowledge of wild boar movement along the border will be useful to describe the extent of the control area for the implementation of specific monitoring programs. The baiting technique used was more cost-effective and has no stress for collard animals, although it is laborious for personnel in an area with dense forest cover and in a bad climate.

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Authors' contributions

Xiaolong, Wang conceived and supervised the entire study. Fekede Regassa, Joka compiled and pre-processed the data and carried out the analysis, as well as the field survey. The two authors participated sufficiently in the research to be accountable for all aspects

Competing interests

The authors declare that they have no competing interests.

Ethical approval

The Animal ethical guidelines are followed in the study for species observation & identification.

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Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Barrios-Garcia, M.N., Ballari, S.A., 2012. Impact of wild boar (Sus scrofa) in its introduced and native range: A review. Biol. Invasions 14, 2283–2300. https://doi.org/10.1007/s10530-012-0229-6
2. Baubet, E., Brandt, S., Vassant, J., Gendner, J., 2004. Can wild boar be surveyed using GPS ? Mem. Natl Inst. Polar Res. 188–195.
3. Cai, J., Jiang, Z., Zeng, Y., Li, C., Bravery, B.D., 2008. Factors affecting crop damage by wild boar and methods of mitigation in a giant panda reserve. Eur. J. Wildl. Res. 54, 723–728. https://doi.org/10.1007/s10344-008-0203-x
4. Carroll, C., Miquelle, D.G., 2006. Spatial viability analysis of Amur tiger Panthera tigris altaica in the Russian Far East: The role of protected areas and landscape matrix in population persistence. Appl. Ecol. 43, 1056–1068. https://doi.org/10.1111/j.1365-2664.2006.01237.x
5. Casas-Diaz, E., Closa-Sebastià, F., Peris, A., Miño, A., Torrentó, J., Casanovas, R., Marco, I., Lavín, S., Fernández-Llario, P., Serrano, E., 2013. Recorded dispersal of wild boar (Sus scrofa) in Northeast Spain: Implications for disease-

monitoring programs. Wildl. Biol. Pract. 9, 19–26. https://doi.org/10.2461/wbp.2013.ibeun.3

6. Chiba, T., 1964. Geographical distribution of wild boars and deer in the Japanese Islands and their areal and quantitative fluctuations. Geogr. Rev. 37, 575-592. https://doi.org/10.1186/s12860-014-0044-2
7. Delahay, R.J., Brown, J., Mallinson, P.J., Spyvee, P.D., Handoll, D., Rogers, L.M., Cheeseman, C.L., 2000. The use of marked bait in studies of territorial organisation of the European badger (Meles meles). Mamm. Rev. 30, 73–87. https://doi.org/10.1046/j.1365-2907.2000.00058.x
8. FAO, 2014. The Global Platform for African swine fever and other important diseases of swine. Animal Production and Health Report No. 4. Rome.
9. Fattebert, J., Baubet, E., Slotow, R., Fischer, C., 2017. Landscape effects on wild boar home range size under contrasting harvest regimes in a human-dominated agro-ecosystem. Eur. J. Wildl. Res. 1–9. https://doi.org/10.1007/s10344-017-1090-9
10. Fodor, J.T., Jánoska, F., Farkas, A., 2015. The comparative analysis of the habitat use of wild boar in different Romanian habitats, in: Proceedings of the Biennial International Symposium. Forest and Sustainable Development, Brașov, Romania, 24-25th October 2014. pp. 365–370.
11. Fuller, G., Margulis, S.W., Santymire, R., 2011. The effectiveness of indigestible markers for identifying individual animal feces and their prevalence of use in North American zoos. Zoo Biol. 30, 379–398. https://doi.org/10.1002/zoo.20339
12. Jiang, Z.-W., Takatsuki, S., Kitahara, M., Sugita, M., 2012. Designs to Reduce the Effect of Body Heat on Temperature Sensor in Board House of Gps Radio-Collar. Mammal Study 37, 165–171. https://doi.org/10.3106/041.037.0301
13. Keuling, O., Lauterbach, K., Stier, N., Roth, M., 2010. Hunter feedback of individually marked wild boar Sus scrofa L.: Dispersal and efficiency of hunting in northeastern Germany. Eur. J. Wildl. Res. 56, 159–167. https://doi.org/10.1007/ s10344-009-0296-x
14. Keuling, O., Stier, N., Roth, M., 2009. Commuting, shifting or remaining? Different spatial utilisation patterns of wild boar Sus scrofa L. in forest and field crops during summer. Mamm. Biol. 74, 145–152. https://doi.org/10.1016/j.mambio.2008.05.007
15. Keuling, O., Stier, N., Roth, M., 2008. Annual and seasonal space use of different age classes of female wild boar Sus scrofa L. Eur. J. Wildl. Res. 54, 403–412. https://doi.org/10.1007/s10344-007-0157-4
16. Lavelle, M.J., Snow, N.P., Halseth, J.M., VanNatta, E.H., Sanders, H.N., VerCauteren, K.C., 2018. Evaluation of movement behaviors to inform toxic baiting strategies for invasive wild pigs (Sus scrofa). Pest Manag. Sci. 74, 2504–2510. https://doi.org/10.1002/ps.4929
17. Nathan, R., Getz, W.M., Revilla, E., Holyoak, M., Kadmon, R., Saltz, D., Smouse, P.E., 2008. A movement ecology paradigm for unifying organismal movement research, in: Proceedings of the National Academy of Sciences of the United States of America. pp. 19052–19059. https://doi.org/10.1073/pnas.0800375105
18. Ohashi, H., Saito, M., Horie, R., Tsunoda, H., Noba, H., Ishii, H., Kuwabara, T., Hiroshige, Y., Koike, S., Hoshino, Y., Toda, H., Kaji, K., 2013. Differences in the activity pattern of the wild boar Sus scrofa related to human disturbance. Eur. J. Wildl. Res. 59, 167–177. https://doi.org/10.1007/s10344-012-0661-z
19. Öhmark, S., 2006. An application of the bait-marking method for the study of spatial activity of wild boar in southern Sweden. Swedish University of Agricultural Sciences.
20. Oliver, W., Leus, K., 2008. Sus scrofa, wild boar. The IUCN red list of threatened 5pecies. https://doi.org/http://dx.doi.org/10.2305/iucn.uk.2008.rlts.t41775a10559847.en
21. Podgórski, T., Baś, G., Jędrzejewska, B., Sönnichsen, L., Śnieżko, S., Jędrzejewski, W., Okarma, H., 2012. Spatiotemporal behavioral plasticity of wild boar (Sus scrofa) under contrasting conditions of human pressure: primeval forest and metropolitan area. Mammalogy 93, 1–12. https://doi.org/10.1644/12-MAMM-A-038.1
22. Russo, L., Massei, G., Genov, P. V., 1997. Daily home range and activity of wild boar in a mediterranean area free from hunting. Ecol. Evol. 9, 287–294. https://doi.org/10.1080/08927014.1997.9522888
23. Said, S., Tolon, V., Brandt, S., Baubet, E., 2012. Sex effect on habitat selection in response to hunting disturbance: The study of wild boar. Eur. J. Wildl. Res. 58, 107–115. https://doi.org/10.1007/s10344-011-0548-4
24. Scillitani, L., Monaco, A., Toso, S., 2010. Do intensive drive hunts affect wild boar (Sus scrofa) spatial behaviour in Italy? Some evidences and management implications. Eur. J. Wildl. Res. 56, 307–318. https://doi.org/10.1007/s10344-009-0314-z
25. Śmietanka, K., Woźniakowski, G., Kozak, E., Niemczuk, K., Frączyk, M., Bocian, L., Kowalczyk, A., Pejsak, Z., 2016. African swine fever epidemic, Poland, 2014-2015. Emerg. Infect. Dis. 22, 1201–1207. https://doi.org/10.3201/eid2207.151708
26. Truvé, J., Lemel, J., 2003. Timing and distance of natal dispersal for wild boar Sus scrofa in Sweden. Wildlife Biol. 9, 51–57. https://doi.org/10.2981/wlb.2003.056
27. Truvé, J., Lemel, J., Söderberg, B., 2004. Dispersal in relation to population density in wild boar (Sus scrofa). Galemys 16, 75–82.

28. Wyckoff, A.C., Henke, S.E., Campbell, T.A., Hewitt, D.G., Vercauteren, K.C., 2012. Movement and habitat use of feral swine near domestic swine facilities. Wildl. Soc. Bull. 36, 130–138. https://doi.org/10.1002/wsb.96
29. Yu, D., Lina, T., Shaoxian, W., Shunzhong, W., Limin, D., 2004. Quantitative methodologies for ecotone determination on north slope of Changbai Mountains. Chinese J. Appl. Biol. 15, 1760–1764. https://doi.org/10.1017/CBO9781107415324.004
30. Yu, D., Wang, Q., Wang, Y., Zhou, W., Ding, H., Fang, X., Jiang, S., Dai, L., 2011. Climatic effects on radial growth of major tree species on Changbai Mountain. Ann. For. Sci. 68, 921–933. https://doi.org/10.1007/s13595-011-0098-7

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